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WATER RESOURCES ACTIVITIES IN THE UNITED STATES. WATER RESOURCES OF HAWAII

Select Committee on National Water Resources, U. S. Senate

January 1960

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86th Congress
2d Session

COMMITTEE PRINT NO. 20

WATER RESOURCES ACTIVITIES
IN THE
UNITED STATES

WATER RESOURCES OF HAWAII

SELECT COMMITTEE ON NATIONAL WATER RESOURCES
UNITED STATES SENATE

PURSUANT TO

S. Res. 48

EIGHTY-SIXTH CONGRESS

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UNITED STATES
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SELECT COMMITTEE ON NATIONAL WATER RESOURCES

(Pursuant to S. Res. 48, 86th Cong.)

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STATEMENT BY THE CHAIRMAN

JANUARY 12, 1960.

To the Members of the Select Committee on National Water Resources:

At a meeting of our committee held on June 11, 1959, it was agreed that in our consideration of water problems under the provisions of Senate Resolution 48, separate and specific attention should be given to the problems of Alaska and Hawaii. This agreement was reached because in many respects the water problems of the two newest States are far different from those of the contiguous States of the United States, and they have not had the benefit of the longstanding water resources programs which have been carried out in the older States.

In view of the interest and responsibility of the Department of the Interior in the affairs and problems of Hawaii during the period before it achieved statehood, it was decided to ask the Secretary of the Interior for a report covering the water resources of Hawaii. We asked that an analysis be made of facts presently known about the water resources of the Hawaiian Islands and their potentialities for development. Among other things it was suggested that the report should present an appraisal of the future water supply-demand situation resulting from the growth in urban and military requirements; potentialities for future irrigation and electric power development; and water developments which could benefit the recreational industry.

The Department's report points out that the Hawaiian Islands receive an abundant rainfall, but that because of unequal distribution of precipitation as affected by the mountains, and because of seasonal variations in precipitation there are several areas with recurring water shortages; however, the Department believes that the water problems of the islands can be solved if the economic problems relating to the development of the water resources can be solved, as the water resources are there and can be made available if we are willing to pay the relatively high costs involved.

The information contained in the report will be of interest to Senators and others interested in the water resource problems of Hawaii, and I am having it printed as one of our series of committee prints. The Governor of Hawaii has also submitted a statement on the water problems of his State, at my request, and it is being published along with the reports of the other States in committee print No. 6.

ROB'T S. KERR, *Chairman.*

COMMUNICATIONS

JUNE 18, 1959.

Hon. FRED A. SEATON,
Secretary of the Interior,
Department of the Interior,
Washington, D.C.

MY DEAR MR. SECRETARY: Further reference is made to my letter dated June 15, 1959, concerning the work of the Select Committee on National Water Resources. The committee at a meeting held June 11, agreed that in its consideration of water problems, it should give separate and specific attention to the problems of Alaska and Hawaii, since in many respects these problems may be somewhat different from those of the continental United States.

Because of the long interest of the Department of the Interior in the affairs and problems of both Alaska and Hawaii, it seems but natural that the committee should look to your Department for a large part of this information. We are also writing directly to the Governors of both States, soliciting their views as to their water problems, even though we recognize that the new State government of Hawaii is just in the process of being formed. We expect also that we may receive information from their Federal agencies concerned with development of water and related resources in the two new States.

In the absence of knowledge of just what information may be available in the Department of the Interior concerning available water supplies, present demands, and related problems in Alaska and Hawaii, the following requests are set forth in general terms only. They may be modified following consultation with members of your staff. It is requested that the committee be furnished with reports containing information along the following general lines:

A. ALASKA

An analysis of present developments and of potentialities of future water resource development, and the part it may play in stimulating the growth of the Alaskan economy through 1980, keeping in mind needs which may be felt through the remainder of the 20th century. Among the specific purposes of development which should be given attention are—

1. Hydroelectric potential as related to feasible industrial growth. Cost estimates would be useful.
2. Inland navigation and the improvement of forest and mineral accessibility.
3. Fisheries.
4. Recreational pursuits.

B. HAWAII

An analysis of facts presently known about the water resources of the Hawaiian Islands and their development potentialities, including data on present uses and estimates of expected uses in 1980 and looking even further into the future to the end of the century. Among other things the report should present—

1. An appraisal of the future supply-demand situation resulting from urban and military requirements.
2. Potentialities for future irrigation and electric power development.
3. Water development which could benefit the recreational industry.

We would like this information to be made available in a summary report of not more than about 10,000 words for each of the 2 States, with whatever tables, charts, appendixes, and graphic illustrations as may be considered necessary. It would be most helpful if this information could be furnished the committee by about October 1, 1959.

The committee staff will be glad to discuss any problems which may arise in the preparation of these reports with members of your staff who are assigned the task of preparing these reports.

Sincerely yours,

ROB'T S. KERR, *Chairman.*

U.S. DEPARTMENT OF THE INTERIOR,
OFFICE OF THE SECRETARY,
Washington, D.C., January 6, 1960.

Hon. ROBERT S. KERR,
Chairman, Select Committee on National Water Resources,
U.S. Senate, Washington, D.C.

DEAR SENATOR KERR: We are pleased to submit to the Senate Select Committee on National Water Resources the report entitled "Water Resources of Hawaii" requested by your letter of June 18, 1959.

Twenty copies of this report are enclosed.

Sincerely yours,

ELMER F. BENNETT,
Under Secretary of the Interior.

CONTENTS

	Page
Statement by the chairman	III
Communications	v
Introduction	1
Occurrence of water	1
Precipitation	1
Figure 1.—Principal islands of Hawaii	2
Hydrologic effects of island geology	3
Figure 2.—Variability of rainfall in the Hawaiian Islands	4
Streamflow	5
Figure 3.—Flow duration charts for selected streams of Hawaii	6
Ground water	7
Quality of water	7
Use of water	7
Water problems	8
Hawaii	9
Maui	9
Lanai	9
Oahu	9
Kauai	9
Major problems	9
Fish and wildlife	9
Recreation	11

WATER RESOURCES OF HAWAII

INTRODUCTION

The purpose of this short statement is to present the water resources, water use, and the problems related to use of water in the Hawaiian Islands. In general, the islands receive abundant rainfall but because of unequal areal distribution related to the effect of the mountains and some seasonal variations there are several inhabited areas with recurring water shortages. Also, many fertile acres could produce crops if water were supplied. In the descriptions, which follow, of the occurrence, availability, use, and shortages of water, particular problem areas on each of the islands will be treated in detail. It will be shown that solution of the water problems of the islands are mainly matters of economics. The water resources are there and can be made available for a relatively high cost.

OCCURRENCE OF WATER

The water resources of the Hawaiian Islands are more closely related to local rainfall than those of the continental United States. Snow is insignificant, although it does occur at high altitude on the peaks of Hawaii. In the United States a home or a farm may use water that fell as rain many miles away. In general in the Hawaiian Islands, because of the high permeability of surface deposits and the peculiarities of terrane, rainfall does not run over the land surface very far before infiltrating. Streamflow results from only the most intense rates of rainfall on such porous islands as Hawaii. However, on other islands, there are some perennial streams where impervious soils have developed or where impervious lava flows exist.

PRECIPITATION

Rainfall in the Hawaiian Islands is extremely variable with time and place. The island topography is a prime factor in the occurrence of precipitation. Moisture laden northeast trade winds are forced to rise as they pass over the islands causing much rainfall on the windward slopes. Although rainfall decreases rapidly with descending elevation on the mountain slopes, the net effect does not produce as pronounced "rain-shadows" as might be expected. The close relationship of rainfall to topography is responsible for the extreme variations in annual rainfall, which occur within a few miles on most of the islands.

Average annual rainfall in the Hawaiian Islands varies from a minimum of 6.5 inches on the lee side of Mauna Kea on Hawaii to more than 450 inches on Kauai. On each of the five islands of Hawaii, Maui, Molokai, Oahu, and Kauai, (see fig. 1) annual rainfall ranges from less than 18 inches to more than 250 inches. On the major island of Lanai it ranges from 10 inches to slightly less than 40 inches. The maximum annual rainfalls on Maui and Hawaii occur, not at the crests of their high mountains, but at elevations of 2,000 to 3,000 feet on the windward slopes. On the other islands which do not have such high peaks, maximum annual rainfall occurs at the top of the ridges.

The rainfall at any place on each major island is determined by its altitude and location with respect to the major mountain ranges. On Hawaii, largest of the islands, two volcanic peaks, Mauna Loa and Mauna Kea, over 13,000 feet in altitude, dominate the topography. Two lower peaks, one close to the north end of the island and the other near the west coast, markedly influence the occurrence of rainfall. Along the windward slopes of the rugged mountains on the northeast coast of Hawaii, annual rainfall is about 75 inches at sea level and rapidly increases to more than 300 inches within 10 miles of Hilo. In the rain shadows of the mountains along the northeast coast and on the very high slopes of Mauna Loa and Mauna Kea annual rainfalls are low. Contrary to the normal relationship of rainfall,

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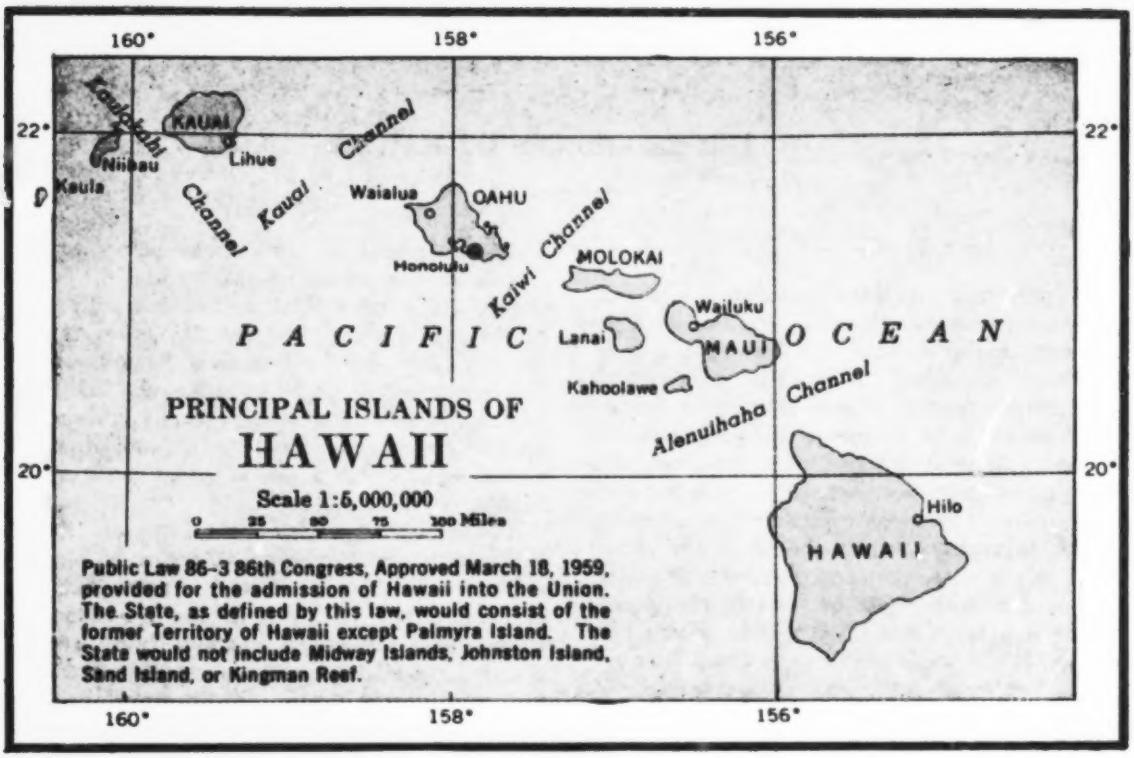

FIGURE 1

topography, and orientation to the northeast trade winds, annual rainfall on the west-facing Kona coast of Hawaii increases rapidly from 20 inches at sea level to more than 100 inches less than 10 miles from the sea.

Maui, like Hawaii, has great extremes in topography and associated extremes in rainfall. Maui is dominated by two great peaks, Haleakala, over 10,000 feet high, and Puu Kukui, nearly 5,800 feet high. Haleakala, near the center of the eastern and larger part of the dumbell-shaped island, intercepts the northeast trades so that annual rainfall varies from about 75 inches at sea level to more than 300 inches at 2,000 to 3,000 feet altitude on the windward slopes. In the rain shadow of Haleakala, average annual rainfall is less than 10 inches at Kamaole. On the western, smaller part of the island, average annual rainfall increases to more than 400 inches at the crest of the ridge. At sea level in Lahaina, on the west coast, median rainfall is 14.5 inches.

On Molokai average annual rainfall varies from a low of less than 15 inches at sea level to more than 250 inches at the crest of the ridge. On Lanai, which is about 20 miles downwind from Puu Kukui on Maui and is not as rugged in topography (highest point is about 3,400 feet altitude) as the other major islands, average annual rainfall varies from 10 inches to more than 37 inches.

Rainfall distribution on Oahu is affected by the major range (Koolau) along the northeast coast and major mountains (Waianae) along the west coast. Average annual rainfall varies from about 50 inches at Kaneohe Bay to more than 300 inches atop the Koolau range. Atop the Waianae Mountains, average annual rainfall exceeds 80 inches. In the lowland at Pearl Harbor, average annual rainfall is about 22 inches. The great variation in rainfall is well demonstrated by the values at Diamond Head (average annual about 20 inches) and Pauoa Flats (average annual about 160 inches) although only about 7 miles apart. Diamond Head is at elevation 70 feet, Pauoa Flats at 1,800 feet.

On Kauai, which has a nearly perfect cone shape with peak altitude of 5,170 feet, rainfall is extremely heavy on the windward slopes and light on the lee slopes. The average annual rainfall near the peak is about 450 inches. In the rain shadow along the west coast of the island average annual rainfall at sea level is about 20 inches. Kauai receives the heaviest rainfall of all the islands. Total rainfall on Kauai if spread evenly over the island's surface would average more than 100 inches.

Median rainfall values [1] for six major islands are in order of amounts:

Island	*Inches*
Kauai	99
Hawaii	75
Maui	75
Oahu	58
Molokai	42
Lanai	21

[1] "Water Resources in Hawaii," Hawaii Water Authority.

In addition to receiving such abundant rainfall, Kauai is further blessed by having the lowest percentage departures from the normal annual values. Thus, in addition to an overall abundance, Kauai water users can be more certain of their supply. Lanai, which has the least annual rainfall, also has the least dependable rainfall. Low rainfall and its great variability makes water supply problems severe on Lanai.

All of the islands experience large variations in annual rainfall. Notable extremes of rainfall have been measured in parts of the islands. In 1956 on Kauai more than 38 inches of rain fell in a 24-hour period. In 1957, 2 inches of rain fell in 5 minutes near Kaneohe, Oahu. These extreme amounts were not measured at the highest elevations but at low to intermediate elevations. Drought periods occur at low elevations on all the islands. At Hilo, Hawaii, where average yearly rainfall is 140 inches, less than 1 inch falls in occasional months. In the driest parts of Maui, Oahu, Hawaii, and Kauai, it is not unusual to have 2 to 3 successive months with no rainfall whatsoever. The greatest recorded drought occurred on Hawaii in 1953–54 when it did not rain for 17 consecutive months in the vicinity of Kawaihae Bay.

Extreme rainfalls can be as damaging as the severe droughts. The rain comes in such great quantities that the stream channels are greatly flooded causing loss of life and high property damage. The floodwaters rush out to sea doing no one much good, as only a small portion can be infiltrated into the ground during the storm period. The heaviest rainfalls are associated with the "Kona" storms—cyclonic-type storms that occur several times a year and which may account for the bulk of annual rainfall in the areas to leeward of the mountains.

Rainfall in the islands is very seasonal—considerably more rain falls from November to April than from May to October. The Kona region of Hawaii is the only area where summer rainfall exceeds that of winter. In other areas of the islands the difference between winter and summer rainfall is most pronounced at sea level and least at high elevations. At the high elevations where most of the water supplies originate the lack of much variation in monthly rainfall is amazing. Because the major part of island rainfall is associated with the northeast trade winds much more rain falls at night than during the day.

Figure 2 portrays the variability of island rainfall with location and with season.

HYDROLOGIC EFFECTS OF ISLAND GEOLOGY

The islands were built up from the sea floor by volcanic activity. On Hawaii volcanoes are occasionally active. As a result of the volcanic growth of the islands and except for minor amounts of coral and other sedimentary rocks, the entire mass of the islands consist of layers of lava flows of basaltic composition. The lava flows are veneered to form circular domes when they flowed from a single vent or long rangelike domes like the Koolau mass on Oahu which came from a long fissure. Small amounts of intrusive material is found in linear or radial dike systems. The dikes are of great importance to the movement of water through openings in the lava because they are an impervious barrier compared to the permeable lava.

The unweathered lavas are highly permeable. The soils derived from the lavas by weathering are much less permeable. The high permeability of the lava flows is due to the contraction joints normal to the lava flow surfaces, the open spaces along some contacts and the generally porous nature associated with escaping gases.

Porosity and permeability of the terrane is such, in general, that during periods of moderate rain-

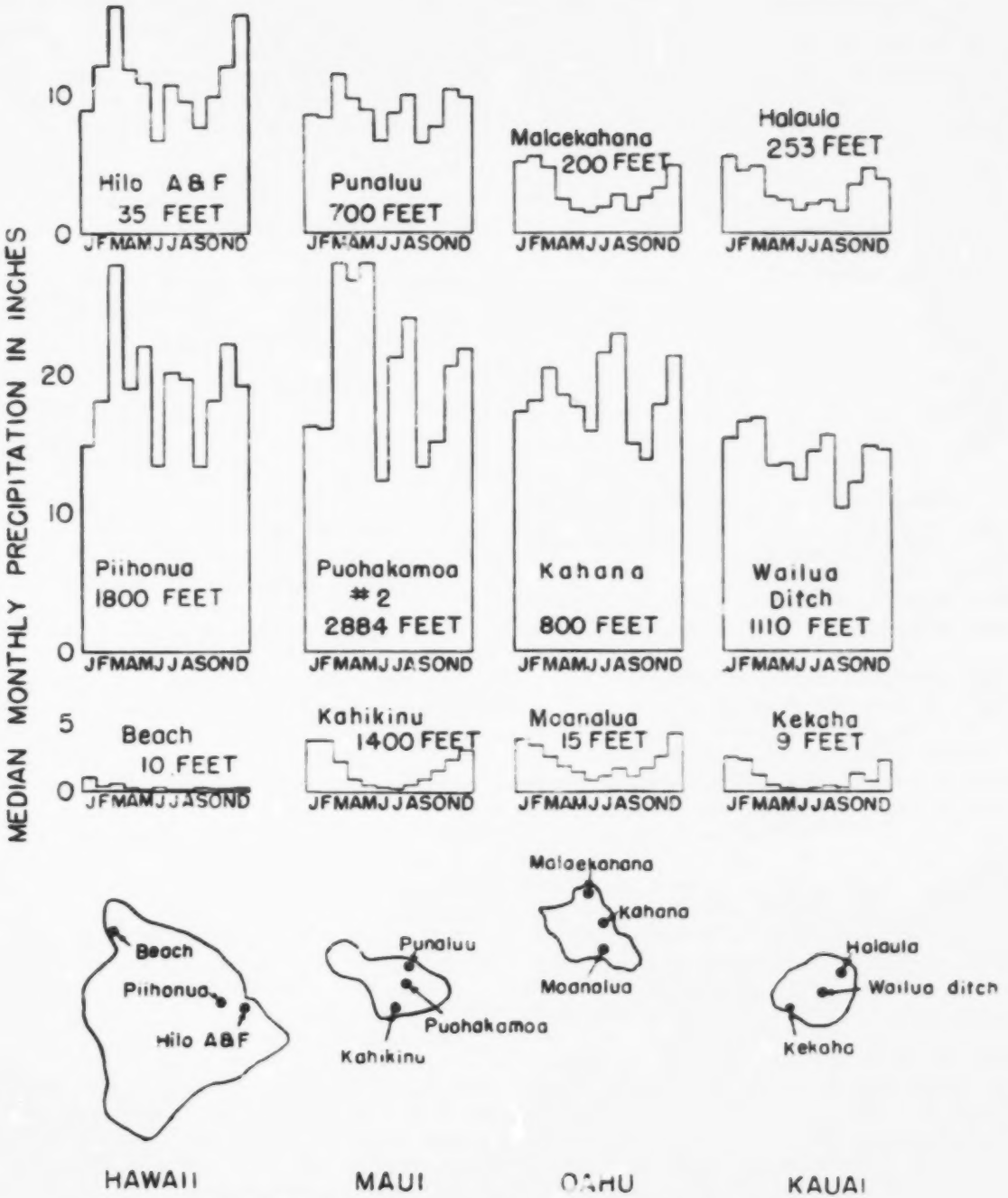

FIGURE 2.—Variability of rainfall in the Hawaiian Islands

fall intensity there may be runoff only in the areas of high elevation and extremely steep slopes. As the streamflow progresses down channel getting further and further from the area of moderate rainfall (rainfall intensities decrease with decreasing altitude) more and more of the water in the channel infiltrates through the channel walls to become part of the local ground w .ter. About two-thirds of the area of the islands fails to produce streamflow in usable quantities. Of course, during periods of highly intense rain some streams may carry water to the ocean.

Where tight soils or "tight" lava flows of little slope occur at high altitudes, mountain top swamps may exist. There may be no free water as one would expect in a true swamp but the soil in these mountaintop swamps may be saturated and provide a significant reservoir for providing perennial seepage to streams. Alakai swamp on Kauai, the largest such swamp in the islands, covers more than 6 square miles and feeds the Waimea River.

Because of the high permeability of the lava material forming the islands conditions are optimum for abundant ground water supplies. The bulk of these supplies occur as basal water floating on salt water, but local geologic conditions may cause other types of ground water to occur. These types—dike impounded, perched water, and shallow ground water—will be described in more detail in the section on ground water.

The type of formations created through volcanism and the effect of weathering from rainfall have combined to produce a characteristic drainage pattern in the islands. The windward sides of the steep mountain slopes are drained by a great many streams each rather deeply incised and with a long and relatively narrow drainage area. In the lee areas where runoff is less the number of streams is much less and they are much less incised. The great number of streams has made it impracticable to gage but a small proportion of them.

STREAMFLOW

Because the lava deposits on Hawaii are highly permeable, streamflow at the high and medium elevations largely seeps into the streambed before reaching the coastline. The permeable streambed deposits, given enough time, can absorb great quantities of water. Only along about one-fourth of the coastline of Hawaii do perennial streams reach the sea. Other islands being "older" geologically have a situation more favorable to the occurrence of streamflow at elevations where water is needed by man. The influence of rainfall characteristics on the streamflow is readily discernible in most of the records. Streams draining the windward slopes have steady flow and very seldom go dry. Streams draining lee slopes are flashy and have long periods of no flow.

Because of the great number of streams in the islands it has not been practicable to gage enough of them to develop a complete picture of the variation of average annual runoff with time and location. Our knowledge of streamflow is much greater for some islands than for others. Little is known about Hawaii, more about Maui, some about Molokai, none about Lanai, quite a bit about Oahu, and most of all about Kauai. Table 1 summarizes streamflow data for each island. Figure 3 presents flow duration charts for streams representative of hydrologic provinces of several of the islands. The streams with most dependable flow have the least slope on the flow duration chart.

TABLE 1.—*Streamflow data for representative streams of the Hawaiian Islands*

Island	Stream	Location of gage		Altitude	Drainage area	Average for period 1945-54	
		Latitude	Longitude			Yearly flow	Yearly runoff
		° ′ ″	° ′ ″	*Feet*	*Square miles*	*Cubic feet per second*	*Inches*
Kauai	Kawaikoi	22 08 00	159 37 15	3,420	4.1	30.5	101
Kauai	Mohihi	22 07 05	159 36 15	3,500	1.6	7.65	65
Do.	East Branch Wailua	22 04 10	159 25 05	500	6.2	52.6	117
Do.	Kalalau	22 09 50	159 38 15	960	1.6	7.32	62
Do.	South Fork Kaukonahua	21 30 05	157 56 50	1,070	1.9	10.3	74
Oahu	Mc naiua	21 22 50	157 32 20	330	2.8	1.78	8.65
Do.	East Branch Manoa	21 19 50	157 48 10	294	1.0	4.13	56
Do.	Pulena	21 07 40	156 49 50	391	4.4	34.2	106
Molokai	Oheo	20 41 05	156 04 10	1,550	5.8	56.6	133
Maui	Alo	20 51 50	156 11 45	1,248	.2	6.31	429
Do.	Waiilikahi	20 07 40	155 59 55	2,740	.4	8.95	304

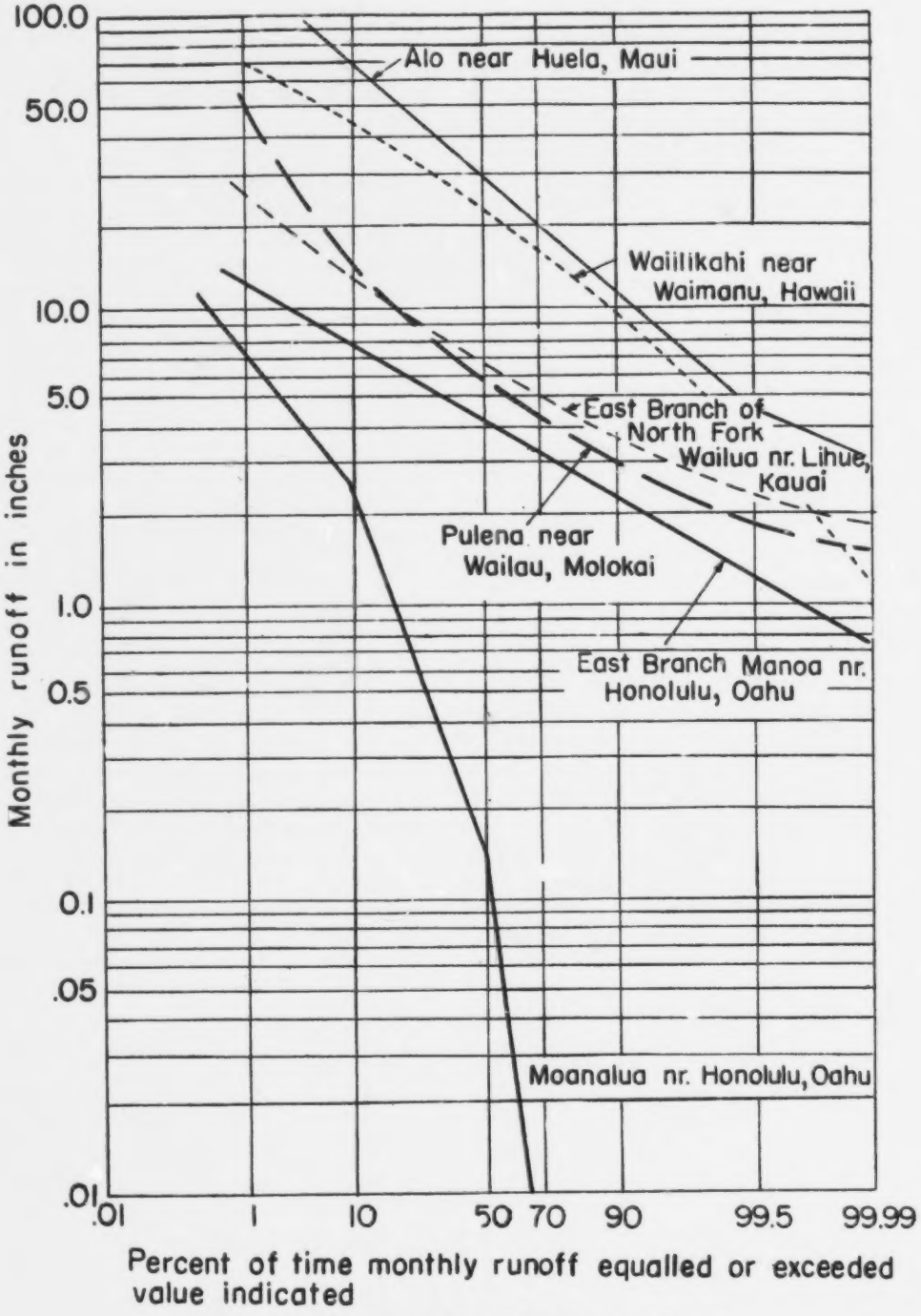

FIGURE 3.—Flow duration charts for selected streams of Hawaii

GROUND WATER

Most ground water in the islands occurs as basal water floating on the salt water from the ocean, which fills the voids of the rock formations at varying depths below sea level. Basal water may occur under water table or artesian conditions. Basal water occurs as a fresh-water lens (Ghyben-Herzberg lens) on each island. The fresh ground water comes from the rainfall that infiltrates directly into the rocks or from streamflow seeping into the rocks from the stream channel. The lens under each island is of variable thickness. Because of the difference in specific gravities of fresh water and salt water, for every foot that the top of the lens of fresh water stands above sea level there must be 40 feet of fresh water in the lens below sea level to maintain equilibrium. If the lens is tapped by pumped wells that lower the water table by 1 foot, the contact of salt water and fresh water will rise, theoretically, by 40 feet. Near the shoreline where the lens must taper to zero thickness the chances of contaminating the fresh with salt water are high. Furthermore, because of the rapid rise in elevation of land surface with distance away from the coastline, ground water is closest to land surface near the seacoast. The place where the least drawdown of water table can be tolerated is the place where one would logically expect to put in a well.

The major hazard in using basal ground water is the danger of salt water contamination caused by drawdown of the water level. Interference between two wells can be particularly hazardous because of the greater local lowering of the water table in the zone of interference. Wise management of the ground water resources to develop maximum potential without sea water contamination requires detailed knowledge of withdrawals, recharge, and water-bearing formations.

Ground water impounded by impervious dikes is a valuable source of water on Oahu. It may be developed on other islands. In some places the impounded water may be found at high altitude and will flow by gravity into a tunnel drilled into the formation. The quantity of such waters depends on rainfall, infiltration rates, and the height and tightness of impounding dikes.

A few deposits of ground water occur as perched bodies of water. On Hawaii, such water has been developed for use by tunneling into the ash beds in which the water was contained.

Ground water, because of its year-round availability, is much used. About 40 percent of the total water supply in Hawaii comes from ground water. Most of the State's domestic supply comes from ground water and on Oahu and Maui ground water is an important source of irrigation water. Because of the impervious nature of the near-surface deposits of the coastal plain in the Honolulu-Pearl Harbor area, wells tap basal ground water under artesian heads ranging from 15 to 30 feet. Although use of ground water is heavy in this area, the artesian head appears to have recovered more than 5 feet since the extremely heavy draft of World War II.

QUALITY OF WATER

Unless there is contamination from sea water, the quality of ground water in the State is always excellent. The basaltic lavas through which the ground water percolates are sparingly soluble, so ground water is soft and dilute. Silica is the principal dissolved constituent. Analyses of the Honolulu water supply show a range in dissolved solids from about 200 to 400 parts per million, of which sodium chloride is an appreciable part.

There are present and potential pollution problems in the islands, especially on Oahu. Honolulu sewage is not treated. Principal bathing beaches are unaffected yet but may be threatened in the future. If plans for bauxite mining mature on Kauai, there may be a manmade sediment problem. Currently, return waters from irrigation projects carry some nitrates (from fertilizers) in solution and these show up in the ground water supplies where return flows recharge the aquifers.

USE OF WATER

Hawaii has a long history of irrigation. Some ditches, constructed for transport of irrigation water during the monarchy, are still in use. A ditch was constructed on Kauai to irrigate sugarcane in 1856. Water used for irrigating sugarcane exceeds all other uses combined. Pineapple and other diversified crops are now raised by irrigation. Data in table 2 were taken from a report by the Hawaii Water Authority.

Water requirements of irrigated crops vary with the crop and the location of the field. Water for

sugarcane is applied at rates between 8 and 9 acre-feet per acre per year. In some dry areas where plentiful water is available, more than 10 acre-feet per acre are applied. For truck crops between 1½ to 3 acre-feet of water are applied per acre per year. For alfalfa about 5 acre-feet per acre per year are used. Pineapples were until recently raised without irrigation. About one-half acre-foot per acre per year is currently being applied to pineapples.

Although there are important economic and strategic reasons why Hawaii should be self-sufficient, the State cannot feed its own people at the present level of population and development. Irrigation of food crops and forage could assist in overcoming the imbalance which now exists.

Table 2 demonstrates the use of water in the various islands and for the State by type of use and source of water. About 75 percent of the total water used is for irrigation, totaling 522 billion gallons or 16,000 acre-feet annually. Present irrigation water use is concentrated on three islands: Maui, Kauai, and Oahu. Although some projects have been built to provide a central water supply to substantial areas, most of the irrigated farms are individual or corporate ventures, diverting surface streams or pumping ground water for single farms. Many scattered small farms use irrigation water on an irregular or intermittent basis.

TABLE 2.—*Water use data as of 1957*

[Use in million gallons per year]

	Island						
	Kuai	Oahu	Maui	Lanai	Molokai	Hawaii	Total
Type of use							
Domestic	3,115	24,410	2,203	90	438	3,880	34,136
Irrigation	156,909	141,835	205,921	522	513	16,129	521,829
Livestock	30	173	25		25	154	407
Industrial	23,826	28,429	11,483	46	60	70,794	134,638
Other	14	914	6,274			2,908	10,110
Total	183,894	195,761	225,905	658	1,036	93,865	701,140
Source							
Surface	168,520	28,619	129,337		412	83,746	410,634
Ground:							
Basal	14,543	149,060	96,092		640	8,542	268,877
Others	695	18,082	477	658	3	1,577	21,492
Unidentified	136				1		137
Total							701,140

Development of Hawaii's water resources for irrigation is now under the sponsorship of the Hawaii Water Authority (formerly the Hawaii Irrigation Authority). This agency operates existing projects, is building others, and has others under investigation.

The Waimanalo project on Oahu, serving about 900 acres, has been in operation since 1953. An experimental farm is operated by the University of Hawaii on this project. The crops grown are largely vegetables and flowers for local consumption and alfalfa for stock feed.

The Waimea project on Hawaii is essentially completed and present activities are concentrated upon problems of service to lands and arranging finances for repayment. This project is designed to serve about 1,200 acres of land. A distinctive feature is the 60-million-gallon reservoir, which is concrete lined on three sides and has a compacted clay bottom.

The Molokai project on the island of Molokai is now under construction, with work on the 5-mile tunnel under contract and well advanced. The plan involves diversion of surface and ground water through the tunnel from the rainy to the drier side of the island for the irrigation of about 13,750 acres of land, largely devoted to pineapples. This project, which may ultimately cost $10 million, has been studied and reported upon by the Bureau of Reclamation.

Other projects which have been studied in some detail are the Kula project, island of Maui, the Kokee project, island of Kauai, and the Waianae project, island of Oahu. Several other potential areas remain to be investigated.

There are 23 hydroelectric plants in the islands. Nine are on Kauai, four on Maui, and nine on Hawaii. The largest single hydroelectric plant is the Kahela station on Maui, which has a rated capacity of 4,000 kilowatts. Much of the water used to generate power is reused for irrigation.

WATER PROBLEMS

The major water problem in all of the islands is one of adequate supply for expansion of man's activities. As the population of the islands is increasing rapidly—it more than doubled between 1930 and 1959—the demand for water is also increasing rapidly. Much of the increase in demand on Oahu arises from the greater per capita demands as well as the greater number of people. There are sizable tracts of land on each of the

islands that could be agriculturally productive if adequate water could be found for them. Many problems arise because of the lack of complete knowledge about ground water. The problems facing each of the islands are set forth below.

Hawaii

A shortage of water exists all along the west shore except at the city of Kawaihae. The Kona portion of the west coast suffers from water shortages during the winter when the cyclonic storms fail to bring expected water. Solution of the supply problem on Hawaii lies in drilling wells to tap the proven ground water resources.

Maui

The Kula district west of Haleakala Mountain suffers from continuing water shortages. The area is in the rain shadow of the mountain and receives, on the average, little more than 20 inches rainfall per year. The rainfall is quite variable resulting in severe droughts some years. Because of the height of land above sea level, drilling of wells to the basal ground water is not economical. Solution of the problem lies in enlarging the Kula pipeline to bring more water from the "wet" side of the island.

Molokai

The need for improved water supply is greater on Molokai than on any of the other islands. The arid lands on the "dry" side of the island represent the best agricultural lands and could be productive of more than grazing and pineapples if water could be supplied. Some relief will come after completion of the Hawaii Water Authority's tunnel to the windward side of the island.

Lanai

Because of low annual rainfall the water resources of Lanai may never be developed more than they now are. Several thousand acres of pineapples are now irrigated from ground water supplies.

Oahu

There are two areas on Oahu where supply problems exist. The first is the northeast coast which has recently been developed as a residential area and future water demand is likely to exceed local supply. The southern portion of this coast does not have the potential supply to meet the potential demand.

The second area is Waimanalo, southeast of Kaneohe Bay. Here development as a residential area is being retarded because of inadequate supply. Local streams and aquifers can't meet the potential demand. Solution of the shortage lies in importation of water from north of Kaneohe Bay.

The general residential area extending along the southwest coast from Pearl Harbor to Waianae Kai Forest could be expanded much if adequate water supply could be provided. The water could be imported from the Pearl Harbor area.

Kauai

Kauai has a general abundance of water. Because the island is older and weathering has produced a thicker soil mantle, there is much greater streamflow on Kauai than on other islands of the group. A few small areas troubled by shortages could solve the problem by constructing reservoirs.

MAJOR PROBLEMS

Determination of the safe yield of aquifers on all the islands without causing salt-water encroachment is of paramount importance. Investigations to develop a full knowledge of aquifer characteristics and the optimum spacing of wells are sorely needed. Investigations to define the extent and water potential of aquifers formed by impervious dikes are also in great need.

Because surface supplies are the least expensive to develop at moderate to high altitude, surface reservoirs need to be built to increase dependable yields. Detailed searches for sites of surface reservoirs might locate several that could be developed without serious seepage loss. Many smaller surface reservoirs can be paved with some form of watertight membrane. Research might show the least expensive way to pave them.

Studies leading to greater diversification of crops might show that sugarcane production ought to be reduced in favor of crops requiring less water as the demand for water approaches the total supply.

FISH AND WILDLIFE

Water resource development in Hawaii has been concerned largely with two needs: (1) Flood control and (2) water for crops. Projects for recreational purposes such as that for the Waiakea Mill Pond in Hilo represent a relatively new trend in Hawaii.

Flood control projects have been carried out largely by the Corps of Engineers, Department of the Army, and in general these projects have been concerned with the enlargement and diking of stream and drainage channels. The enlargement of such channels may provide an improved habitat for fish since the channels may now be permanently filled with water. In some instances they supply good habitat for bait fish for tuna fishermen and in others recreational fishing for mullet and the introduced tilapia may be had.

Where local interests have dug drainage canals and drained swampy areas, a corresponding reduction in habitat for waterfowl and wading birds has occurred. It is hoped that the Fish and Game Division of the State of Hawaii will maintain existing sanctuaries, such as Kanaha Pond on Maui, for waterfowl and wading birds, and that steps will be taken to establish others for the preservation of unique endemic species such as the Hawaiian stilt.

Kaelepulu Pond was drained by private interests for housing development purposes. This pond, the largest body of freshwater on Oahu, had been used yearly by thousands of migratory waterfowl as a feeding and resting ground.

The development of water resources for agriculture has followed a somewhat different pattern. Historically, this development has been done by private enterprises in order to irrigate the dry leeward areas of the islands for sugarcane. This has been done by diverting stream water from the wet windward areas by constructing a channel or ditch parallel with the contours of the land at a substantial elevation to catch all or part of the streams which cross this channel. This, of course, tends to reduce the volume of flow in these streams at elevations below the diversionary ditch, and this has had a noticeable effect upon the abundance of one species of desirable fish present in these streams. This species is a freshwater goby, *Awaous guamensis*, which runs downstream to the last rapids above tidewater for spawning. The eggs are attached to stones in this portion of the streambed and the larval fish, after hatching, are washed out to sea where they remain for a period of approximately 6 months. They reenter the stream after their sojourn in the sea and migrate back upstream to the headwaters, a migration sometimes prevented by either greatly reduced flows or diversionary irrigation structures. While the goby provides food for people locally, the value of the goby resource is comparatively low. Therefore, there is no real argument against such diversions and appropriate action should be to stock streams, above the irrigation diversions, with other species of fish which do not require a trip downstream in order to reproduce. One species which seems ideal for this purpose is a South American catfish, *Astroblepus grixalvii*, which lives in torrential stream conditions in the Andes. This species is approximately the same size as the goby and is a highly valued food fish in its native environment.

In areas where streamflow is not too rapid, such as the Kokee area of Kauai, the introduction of trout has been carried out with considerable success.

The impact of these irrigation developments upon wildlife has been relatively slight, except insofar as the agricultural use of the land itself is concerned. This has resulted, through current methods of clean cultivation, in a reduced habitat for some of the game bird species, such as pheasants, doves, and quail.

Below is a partial list of proposed projects involving water resource development with comments on their possible effects on fish and wildlife. Some of these projects are of a tentative nature.

1. Major irrigation development on Molokai involving the diversion of the Waikolu stream, from a deep windward valley to the plains of Hoolehua. This will greatly reduce the stock of stream gobies and freshwater limpets in Waikolu Valley.

2. Conversion of Kaupa fish pond on Oahu (over 300 acres) to a residential boating area. This may destroy the habitat of rare wading birds, such as the Hawaiian stilt.

3. Clearing Waiakea Mill Pond, Hawaii, for recreational purposes. This will result in substantially increased fishing and recreational boating on the pond.

4. Kawainui Swamp drainage canal, Kailua, Oahu. Improve fishing but may reduce habitat for wading birds.

5. Construction of a large impoundment (over 400 acres) for power and irrigation purposes in the Kokee area of Kauai. This would provide excellent trout fishing; currently progress on this project seems to be at a standstill.

RECREATION

Water-related recreation centering on the beaches is of prime importance to the tourist industry of Hawaii which yielded $75 million of new money in 1957. Those using the beaches, parks, and monuments also need fresh water for domestic and sanitary purposes. The Hawaii Visitors Bureau has stated that the potential of tourism for Hawaii is virtually unlimited, yet comparatively little has been done to enhance and preserve the outstanding natural and historic features that are the basis for this valuable source of income to the State.

On Oahu there are only three beaches now owned (and controlled) by the State with a total beach frontage of less than 3 miles out of a total coastline of 148 miles. City and county beach parks increase this amount by only 18 miles. These public beaches are now being used to near or full capacity.

With the expansion of population and urbanization, particularly on the island of Oahu there is need for greater park developments to serve residents as well as tourists. Provisional projections by the territorial planning office indicate there may be a 104 percent increase in civilian population of Oahu between 1956 and 1980.

As of January 1959, the territorial parks division of the board of agriculture and forestry administered 13 parks, 2 protected areas, 2 lookouts, 2 hunting camps, and 1 historical display with a total area of 5,847 acres. The largest park is Kokee on Mauai with 4,500 acres. All except Kokee and Palaau lack adequate acreage and all areas need additional facilities for visitor use, including water for domestic and sanitary purposes.

During the 12-month period ended June 1957, 180,000 persons visited the territorial parks according to the Annual Report (1956–57) of the Board of Commissions of Agriculture and Forests, Territory of Hawaii.

Hawaii National Park is the only recreational area in Hawaii administered by the National Park Service. It consists of units on the islands of Hawaii and Mauai and had 461,283 visitors in 1958. Visitation by 1966 may be up to between 590,000 and 660,000. Trends suggest there may be between 1 million and 2 million visitors by the year 2000.

The land within the main section of the park on the island of Hawaii is composed of fractured volcanic lava and highly permeable soil having no surface or ground water supplies capable of being collected for use. Water supplies in the Haleakala section on the island of Mauai are similar with the exception of a small supply from springs and from catchment of intermittent streamflow. Nearly all the water for the park is therefore obtained by rainwater catchment. Rainwater supplies also require chlorination and, in the case of the main supply at Kilauea, filtration to remove leaves and other material windblown onto the catchment works. No special difficulties exist in connection with rainwater catchment systems other than the necessity of providing sufficient catchment and storage facilities to carry over dry periods, and constant attention to prevent debris from entering the reservoirs.

There are 15 areas in the Kilauea section of the park on the island of Hawaii with catchment areas and storage including one development for a military installation. Some additional picnic areas and patrol cabins are supplied with water which is hauled from the headquarters area on that island. There are also five areas in the Haleakala section on the island of Maui, which are supplied with rainwater and partial supplies from springs and intermittent springs.

Storage at individual developed areas in the Kilauea section varies from 300 gallons at Foot Print to 3,003,000 gallons at the military installation and 3,340,000 gallons at the park headquarters area. Precipitation varies from 15 inches at Halape to about 100 inches at the headquarters. Considerable additional water can be made available with increased storage or catchment area, or both, but the roofs of buildings now provide most of the catchment areas, and about 2.29 acres are now devoted to that purpose at headquarters and there are between 4 and 5 acres at the military installation.

Conditions in the Kilauea section are similar as they relate to stored precipitation catchment, but three areas have supplemental supplies from

springs and intermittent streams, about which more information has been requested but not yet received.

Quadrupling park attendance can be handled in most cases by increased storage and catchment areas, but maintenance and operation of the individual units, particularly the collection from numerous roofs with little more than 300 square feet of areas, involves detailed operating procedure. Salt water conversion, and even remote commercial supplies, might be considered in the future, but these alternatives will not usually be justified except for the larger developed areas because of the distances and pump lifts.

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